A Fully Automated High-Accuracy RF/IF Test System for Millimeter- and Submillimeter-wave Mixers

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ABSTRACT

An automated RF/IF test system for complete, accurate measurement of millimeter and submillimeter-wave mixer performance is described. Improved ability to measure mixers with high IF output impedance over a 1-18 GHz bandwidth has been achieved through the use of an automatic tuner and swept scalar reflection measurement. An accurate means of measuring mixer sideband response over a wide IF range is also described.

I. INTRODUCTION

A rudimentary mixer noise figure measurement system merely consists of reference loads, an amplifier, isolator, filter and a power detector [Fig. 1]. While low in complexity and cost, such a system contains many sources of error. Mismatch between the mixer IF output and isolator input is not accounted for, nor is the excess noise introduced into the measurement by the isolator and mixer IF cable. Some mixer measurement systems have been constructed that address these errors [1]; however, there is still room for improvement. Even though the mixer IF output impedance is measured and accounted for, the mismatch due to the isolator and interconnecting cable presented to the mixer IF input can cause the actual mixer-test system mismatch to be greater or less than expected from the mixer IF reflection measurement. This can lead to significant error when measuring the noise temperature of mixers with high IF output impedance. In addition, it is often desirable to obtain the single sideband (SSB) noise temperature of a double sideband mixer over a given IF bandwidth. This can be an extremely time consuming process if calibrated sources are not available and one has to resort to noise sources and high Q tunable filters [2].

We describe a millimeter- and submillimeter-wave mixer test system that addresses the above error sources and allows accurate automated sideband measurements over a 1-18 GHz bandwidth. The RF bandwidth of the system extends from 160 GHz to well over 700 GHz (limited only by input optics), and the IF bandwidth is 1-18 GHz. Accurate measurement of available mixer noise temperature and conversion loss is made possible by keeping the IF input return loss extremely low through the use of an automatic tuner [3], and through the use of a swept method to measure the mixer IF reflection coefficient. This provides accurate results even when there is a large mismatch at the mixer IF port as is the case when measuring mixers with high IF output impedance.

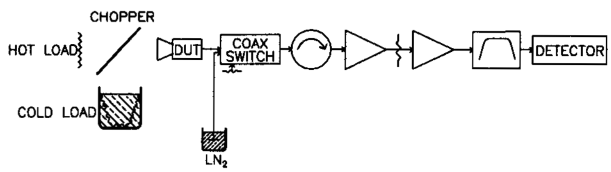

Fig. 1: Simple mixer test system

II. TEST SYSTEM DESCRIPTION

Two fixed RF reference loads consist of a tank containing liquid nitrogen-bathed foam absorber, and a load at ambient temperature. These two loads are switched by a chopping mirror and focused into the mixer via two off-axis ellipsoidal mirrors. The mirrors provide a beam waist for a Fabry-Perot interferometer (FPI), which is inserted between the mirrors when mixer sideband ratio measurements are to be performed. A hand-held cold load is used close in to the mixer under test to determine the effective brightness temperature of the fixed cold load during initial test set calibration.

A simplified block diagram of the IF portion of the test system is shown in Fig. 2. The coax switch at the input switches accurately characterized IF hot and cold loads for calibration. The temperature of the ambient hot load is measured with a sensor, while the effective temperature of the cold load at the system reference plane (input coax switch) is derived from the loss of the stainless steel coax cable connecting the liquid nitrogen-bathed coaxial load to the switch [1].

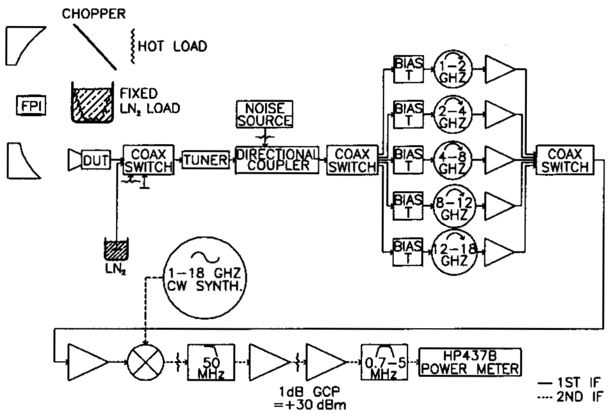

Fig. 2: Block diagram of test system IF section

The automatic tuner is calibrated during system construction and set during measurement to provide a minimal return loss at the coax switch input at any IF frequency. The directional coupler and noise source are used as a scalar reflectometer for measuring the mixer IF output reflection coefficient. The bias tees (located beyond the calibration plane at the input coax switch so that their losses are calibrated out), isolators and first IF amplifers are split into 5 bands to keep the test system noise temperature low. Following a second 1-18 GHz amplifier is the mixer which downconverts the 1-18 GHz first IF to a 0.7-5 MHz second IF. This provides for an effective IF bandwidth of 8.6 MHz. Larger bandwidth is not possible due to the narrow instantaneous tuning bandwidth of the automatic tuner. To guarantee system linearity, the 1 dB compression point of the final IF amplifier was chosen to be 20 dB greater than the maximum output power seen during a measurement. A normal measurement output power range of 0-10 dBm allowed the use of a standard thermocouple-type power meter head (HP8482A).

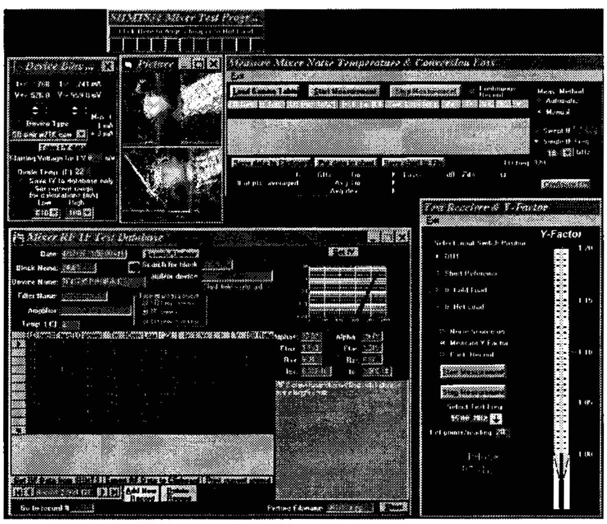

Fig. 3: Test system user interface

The entire test system is controlled by a 166 MHz Pentium® computer running Windows NT® operating system. Software written in 32-bit Visual Basic® controls all hardware and provides a multi-windowed user interface that provides simultaneous access to mixer bias control, IF frequency selection, real-time Y factor display for rapid mixer tune-up, Fabry Perot interferometer positioning and mixer noise temperature and conversion loss measurement [Fig. 3]. Critical factors that affect data accuracy versus measurement time such as integration time, IF frequency resolution and interferometer step size are easily adjusted by the user. A routine is provided to recalibrate the automatic tuner with a vector network analyzer should it become necessary to service the tuner. All acquired data is seemlessly exported to a database that provides powerful search capabilities. A/D-D/A, digital I/O, counter and GPIB expansion boards in the computer provide mixer bias as well as communication with GPIB devices and stepper motor controllers.

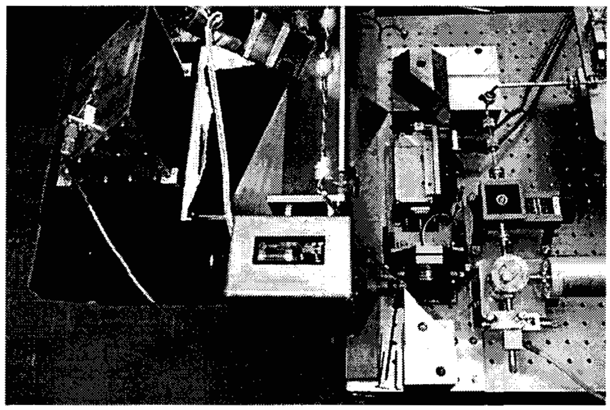

Fig. 4: Photo of test system RF section. A 240 GHz mixer under test can be seen at lower right

III. MEASUREMENT METHOD

The IF portion of the system is calibrated by measuring its noise temperature using the switched IF hot and cold load [4]. The scalar reflectometer is then calibrated by measuring the noise temperature of the input when connected to a short with the noise source on and off. Unlike the hot-cold measurement, this measurement is done with the IF swept over a 140 MHz bandwidth. The width of the sweep and the length of the coax cables in front of the directional coupler were carefully chosen such that the sweep 'averages' the effect of standing waves between the directional coupler and the input switch. This average value is found by performing the same measurement with the input switched to one of the IF loads. By subtracting this value from swept reflection coefficient measurements on the mixer, a substantial improvement in scalar reflection coefficient measurement is obtained without the need for a vector network analyzer. DSB mixer noise temperature and conversion loss measurements are then performed using the formulas described in [1]. Initial calibration at each RF frequency band is performed using a hand-held cold load directly in front of the mixer, then the fixed liquid nitrogen-bathed load. The effective temperature assigned to the fixed nitrogen load is then increased until the same noise reading is obtained. The effective T_{COLD} is found to be 82-95 K depending on RF frequency.

Once the mixer DSB noise temperature and conversion loss have been found, the response of the mixer in the lower and upper sidebands can be determined by measuring the relative ratio of lower to upper sideband conversion loss. Using a parallel grid Fabry Perot interferometer of appropriate Q [2], the conversion loss of the mixer is measured as a function of grid spacing at fixed IF frequency.

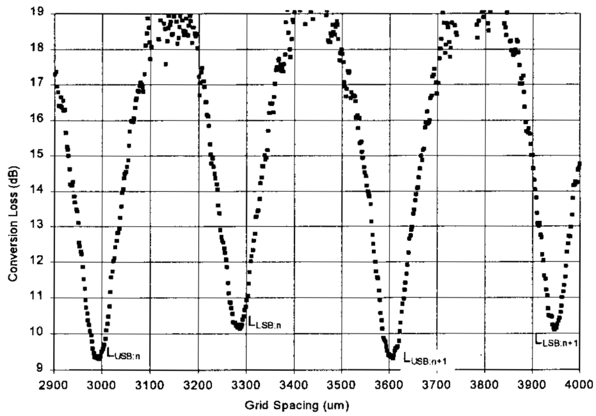

Fig. 5: mixer conversion loss as a function of FPI grid spacing

In Fig. 5, the sideband ratio can be seen graphically as the difference in conversion loss between the two adjacent nulls. The plotting of multiple orders provides verification that losses in the FPI are sufficiently constant with respect to grid spacing that there is no contribution to measured sideband ratio [5]. From the above data and knowledge of the DSB noise temperature and conversion loss, the single sideband noise temperature and loss can be found simply from:

$$T_{M\,LSB(USB)} = T_{M\,DSB} \cdot \left(1 + \frac{L_{LSB(USB)}}{L_{USB(LSB)}}\right)$$

$$L_{LSB(USB)} = L_{DSB} \cdot \left(1 + \frac{L_{LSB(USB)}}{L_{USB(LSB)}}\right)$$

where L_{DSB}, L_{LSB}, L_{USB} are all in linear units.

IV. CONCLUSION

A test system for the accurate measurement of single sideband mixer noise temperature and conversion loss at millimeter and submillimeter wavelengths has been described. Due to major reduction of input mismatch and improved scalar reflection measurement techniques, accurate measurement of mixers is possible over a broad IF bandwidth even under conditions of high IF impedance mismatch.

V. ACKNOWLEDGMENT

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V. REFERENCES

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